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NEUTRON FLUX MEASUREMENTS IN A THREE-CAPSULE D_2O TANK IN THE NASA PLUM BROOK MOCK-UP REACTOR

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ABSTRACT

Previous experiments with a capsule surrounded by D_2O instead of H_2O showed that the thermal neutron flux increased ten times in the regions of the HT-2 test hole away from the core. Experiments with a D_2O tank containing three identical capsules were conducted. Compared to a single capsule in H_2O, the sum of the flux in all three capsules was three times higher, the flux in the capsule nearest the core was two times as high, and the flux in each of the other two capsules was one half as high. Gamma heating was also measured.

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SUMMARY

In order to use the HT-2 test hole of the Plum Brook Mock-up Reactor (MUR) more effectively, three tests were run using a three capsule D_2O tank. The tank contained three capsules mocking up circulating gas capsules arranged at 120 degrees about the HT-2 axis. The D_2O tank replaced the water normally surrounding the test capsules. The three tests differed only in the position of the tank, which was rotated 90 degrees between runs in order to investigate the effect of the capsule location on the thermal neutron flux.

The measurements show that the neutron flux at the capsule centerline varied by a factor of 6 depending upon the angular position of the capsule about the tank axis. At the fuel pins, the neutron flux ranged from 4.39×10^{13} neutrons/cm^2-sec when the capsule was nearest the core, to 0.756×10^{13} neutrons/cm^2-sec away from the core. The capsule nearest the core in a three capsule tank had flux levels 26 percent below a single capsule surrounded by D_2O tested in a previous experiment.

Each fuel pin had a fuel loading of 5 grams per inch (2 grams per centimeter) of U^{235}. The fuel in the experiment caused a 26 percent drop in the flux between the three fuel pins. The ratio of the flux incident on the fuel to the flux at the center of the fuel was 3.2:1.

The sum of the flux in the three capsules with D_2O is 1.3 times higher than in a single capsule with D_2O, and three times higher than in a single capsule in H_2O. If the capsule wall material is changed from stainless steel to aluminum, the sum of the flux can be raised to about 1.7 times that of a single capsule in D_2O, and by about 4 times if compared to a single capsule in H_2O.

Gamma heating was measured in one capsule during one run.

INTRODUCTION

The Plum Brook Reactor is a 60 MW test reactor containing a 3 by 9 array of MTR type of fuel elements cooled by light water. The reactor has several test holes for irradiation, located both in the core and in the water on the sides of the core. The test holes in the water region have an uneven flux distribution across the test hole due to neutron absorption by the water. Previous experiments (ref. 1) have shown that the flux levels in a test hole can be raised by surrounding the experiment with D_2O instead of the H_2O normally present in the hole.

In order to investigate the feasibility of operating three capsules simultaneously in a test hole, three tests were run using a D_2O tank holding three experiment capsules side by side in the tank. This was expected to make use of the low flux space which normally was left vacant during an experiment. These tests were conducted in the Plum Brook Mock-up Reactor (MUR), which is a low power mock-up of the 60 MW Plum Brook Reactor, using the HT-2 test hole (figs. 1(a) and (b)). Thermal neutron flux measurements were made to determine whether the flux levels would remain high enough to allow three simultaneous experiments.

DESCRIPTION OF THE EXPERIMENT

This section describes the Mock-up Reactor (MUR), the apparatus used to conduct the experiments in the MUR, and the experiment configurations.

The Mock-up Reactor (MUR)

The MUR (figs. 1(a) and (b)) is a low power swimming pool type of reactor located at the Plum Brook Reactor (PBR) facility (ref. 2). The MUR is dimensionally identical to the PBR, which it simulates. The MUR contains 27 MTR type of fuel elements in a 3 by 9 array, when fully loaded. These are the same as those used in the PBR. Light water not only cools the fuel elements by natural convection, but also serves as moderator and as a secondary reflector. Beryllium is the primary reflector. Typically, the MUR is operated at 10 kW for 20 minutes.

The core used in the MUR at the time of the experiments was designated G (MUR-G). Figure 1(b) shows a top view of the MUR with the U^{235} mass per fuel element in grams shown.

Experiments for insertion into the MUR HT-2 test hole are lowered from the surface of the reactor pool to an insertion table. A hand crank located at the pool edge operates the insertion mechanism which locates the experiment within HT-2.

Experiment Apparatus

The experiment apparatus (fig. 2) consisted of four major parts: the experiment canister, the D_2O tank, the experiment capsules, and the fuel assembly. Each of the three capsules contained one fuel assembly. After the capsules were placed into the holes in the D_2O tank, the tank itself was inserted into the experiment canister, which was then closed and inserted into HT-2. Figure 3 shows the cross section of the D_2O tank with the experiment capsules and fuel assemblies as positioned in run 2.

The experiment capsules together with the fuel assemblies mock up a PBR circulating gas capsule test section (ref. 3). The current PBR capsule is located in the HT-2 test hole at the same position as capsule #1 of figure 3.

Experiment canister. - The aluminum canister was inserted into the HT-2 test hole by means of a handle which engaged the insertion mechanism. The canister was 39.5 inches (100.0 centimeters) long, with an outside diameter of 11.25 inches (28.6 centimeters) and a usable inside diameter of 10.26 inches (26.0 centimeters). One end had a welded hemispherical head, and the other end was threaded to mate with a flat plate which provided a seal with an O-ring. However, for this series of experiments, cooling water was allowed to enter the canister.

D_2O tank. - The aluminum D_2O tank was 10 inches (25.4 cm) in diameter and 31 inches (79 cm) long. Figure 3 show a cross section of this tank together with the three experiment capsules inserted into the three axial holes of the tank. These holes were 3.75 inches (9.52 cm) in diameter. The centers of the holes were 2.5 inches (6.35 cm) from the tank centerline, and were spaced 120 degrees apart. The entire tank was made from aluminum and was filled with D_2O.

Experiment capsules. - Each of the three experiment capsules were made from three-inch Schedule 80 aluminum pipe. This pipe had an outside diameter of 3.5 inches (8.9 cm) and a wall thickness of 0.300 inches (0.762 cm). Each capsule was 31 inches (79 cm) long, with one end closed by a 0.250 inch (0.635 cm) thick aluminum plate. A similar plate was attached to the other end with four wing nuts to provide access to the inside. A stainless steel liner fit inside the experiment capsule to mock up the walls of the stainless steel test section of the capsule of reference 3. The liner was made from $2\frac{1}{2}$ inch Schedule 80 stainless steel pipe, which had an outside diameter of 2.875 inches (7.30 cm) and a wall thickness of 0.276 inches (0.701 cm).

Fuel assembly. - Each fuel assembly consisted of two parts: the fuel pins, and the hardware for positioning the fuel inside the capsule. Figure 4 shows a cross section of a fuel assembly.

The fuel pins were made by rolling a 2-inch (5-cm) wide strip of uranium foil on a 3/16-inch (0.475 cm) outside diameter aluminum tube. The rolled up foil and the aluminum tube were then slipped inside a 0.500-inch (1.27-cm) outside diameter by 0.035-inch (0.089-cm) wall thickness stainless steel tube simulating the coolant gas flow guide. The fuel pins were 11 inches (27.7 cm) long.

The uranium used in the fuel pins was 93.2 percent enriched U^{235}. The following table lists the U^{235} weights in grams for each fuel pin.

K1	10.47	L1	10.05	M1	10.33
K2	10.71	L2	10.98	M2	10.82
K3	9.53	L3	9.62	M3	8.54

The fuel pin locating mechanism was very simple. A 0.250-inch (0.635-cm) diameter aluminum rod extending the length of each capsule passed through the center of two aluminum discs. The rod was used to position the fuel axially, while the discs centered the rod inside the capsule. Three mock-up fuel pins were held between the discs by three small pins in each disc. These pins were spaced at 120 degree intervals about the central rod and 0.500 inch (1.27 cm) from its center. The discs and the fuel pins were moved along the rod to the desired position and then locked to the rod.

Test Configuration

The same hardware was used in each of the three MUR runs. The only difference between the runs was in the angular position of the D_2O tank and the experiment capsules. With two rotations of the tank about the HT-2 axis and using three identical experiment capsules spaced 120 degrees about the tank axis, a total of nine sets of neutron flux measurements could be made. Figure 5 shows the angular positions of the tank and experiment capsules for all three runs.

EXPERIMENTAL METHODS

Thermal Neutron Flux Measurements

The thermal neutron flux levels were measured with gold foils and wires and uranium-aluminum alloy wires. The gold wires were 0.5-inch (1.27-cm) long and 0.03 inch (0.076-cm) in diameter, while the foils were disc shaped with a diameter of 0.250 inch (0.635 cm) and a thickness of 0.005 inch (0.013 cm).

Several of the gold wires had cadmium sleeves. These were mounted at random throughout the experiment capsules and the D_2O tank. Their purpose was to measure the fast flux, as the cadmium sleeves absorbed neutrons with energies below 0.5 MeV. From these measurements the ratio of the fast flux to the total neutron flux was obtained, and thus provided a correction factor for the bare gold wires which measured the total flux.

The uranium-aluminum alloy wires had the same dimensions as the gold wires. The uranium-aluminum wires were used in order to obtain the fission rate directly, which could then be converted to the thermal neutron flux, thus providing a check for the gold measurements. The uranium-aluminum alloy wires were used in the fuel region of the experiment capsule, where they were interspersed among the gold wires.

The gold foils were used on the outside surfaces of both the D_2O tank and the experiment capsule. Their flat shape reduced the chances of being rubbed off during the assembly. The wire dosimeters were used in the remaining positions. The wire dosimeters which were inserted into the fuel pin tubes were taped to 1/16-inch (0.159-cm) diameter aluminum welding rod. This allowed both accurate positioning axially and easy mounting and removal of the dosimeters.

The position of each dosimeter within the experiment capsules is given by the following code. The location of the dosimeter in a plane perpendicular to the test hole axis is indicated by a capital letter. These locations are shown in figure 3. The axial position is indicated by a station number as shown in figure 2. The station number represents the axial distance east of the reactor center line in inches. The location letter and the station number together then give a unique position for each dosimeter.

Tables I and II give the location and station number of each dosimeter used, along with the measured thermal neutron flux value. It should be noted that the flux measurements at the fuel surface (locations K, L, and M) and on the center rod (location J) were made with dosimeters facing the core, except for fuel pins L1, L2, and L3 in run 1, which had four dosimeters each spaced 90 degrees apart. Also, several dosimeter locations were not used in run 3.

Following the irradiation, the dosimeters were counted on a 512-channel pulse-height analyzer using a sodium iodide crystal. The analyzer gave the number of counts under the gold 198 (Au^{198}) photopeak for the gold dosimeters. The uranium-aluminum alloy wires were counted following a 5-day decay period. The pulse-height analyzer counted the activity of the fission product lanthanum 140 (La^{140}) and barium 140 (Ba^{140}).

The count data, elapsed time from reactor scram to counting, dosimeter data (mass and material), dosimeter position relative to the sodium iodide crystal, irradiation time and reactor power level were used as input for a computer program. This program calculated the absolute disintegration rate of each dosimeter. It then corrected this rate to the scram time and calculated the flux per watt of reactor power. The program then print out the neutron flux adjusted to a reactor power of 60 MW and the equivalent fission power generation at 60 MW. The program calculated the thermal flux by correcting the cadmium-covered data for thermal neutron leakage through the covers and subtracting the cadmium-covered data from the bare gold data. Another program performed a similar analysis using the uranium aluminum dosimeters.

Gamma Heating Measurements

The gamma heating was measured by LiF thermoluminescent dosimeters (TLD). These were short plastic rods 0.04 inch (0.1 cm) in diameter and 0.25 inch (0.635 cm) long. They were mounted in the same positions as the neutron flux dosimeters, separated by about 0.125 inch (0.318 cm) from them. Table III lists the dosimeter locations used in run 1 together with the measured gamma heating values. The location and station number code is the same as the one used in the neutron flux measurements.

Following the irradiation, the TLD's were counted and the results were analyzed by a computer program. This gave the gamma heating in watts per gram at a reactor power of 60 MW.

RESULTS AND DISCUSSION

The MUR was operated at 10 kW and a rod bank height of 16 inches (40.7 cm) for 20 minutes for all three runs. The results of the computer analysis of the dosimeter measurements are given in tables I - III. These tables list the thermal neutron flux levels and the gamma heating at a reactor power of 60 MW for each dosimeter position. In order to calculate the fission power generated, the following relation should be used. A neutron flux of 2.13×10^{13} neutrons/cm^2-sec generates 1 kW of power in every gram of U^{235} in the fuel pins.

The uncertainties in the measurements are: ± 18 percent in the absolute flux values, ± 10 percent in the relative flux values, that is, in the comparison of the flux values between runs, and ± 23 percent in the gamma heating measurements.

Neutron Flux Distribution

Figure 6 shows the thermal neutron flux at 60 MW as a function of the angular position of the experiment capsule with respect to the HT-2 axis. The flux levels in this figure were measured at the experiment capsule centerlines (locations J1, J2, and J3). Four curves show the flux distribution at 0.5, 8, 16, and 23 inches (1.27, 20.3, 40.6, and 58.4 cm) east of the core centerline. The fuel pin midplane is perpendicular to the tank and capsule axes, at 8 inches (20.3 cm) east of the core centerline.

Figure 7 shows the thermal neutron flux as a function of the distance east of the core centerline for the three capsules in run 3 as measured at the capsule centerline. This figure also shows measurements made in single capsule experiments using both D_2O and H_2O (ref. 1). The experiment capsule position for these cases was the same as that of capsule 1 in run 3 and the measured fluxes were corrected for the perturbation due to the molybdenum in the single capsule tests. This allows a comparison between the single capsule and the three capsule experiments. Figure 7 also includes curves for the unperturbed flux in HT-2 at the position of the capsule 1 centerline in run 1. The MUR operating staff made these measurements previously, and they are included here as reference points for the experimental measurements.

Figure 8 presents the results of the flux measurements on the surface of the fuel pins L1, L2, and L3 at the fuel pin midplane 8 inches (20.3 cm) east of the core centerline in run 1. It shows the incident flux on the fuel pin surface at 0, 90, 180, and 270 degrees on the circumference.

Effect of angular position. - By using three identical experiment capsules and rotating the D_2O tank 90 degrees about the tank axis between runs, nine distinct angular positions of the capsules with respect to the HT-2 axis were obtained, as described below. In figure 5, run 1 gives measurements at 90, 210, and 330 degrees, while run 2 gives measurements at 60, 180 and 310 degrees, and run 3 at 0, 120, and 240 degrees. The angles were measured from a line through the center of HT-2 and perpendicular to the reactor core north face. This line formed an angle with another line passing through the centers of the experiment capsule and HT-2. The angles were measured in the clockwise direction when looking into HT-2 toward the west. Using this convention, the 0 degree position faces the core, 90 degrees is at the top, 180 degrees faces north, and 270 degrees is at the bottom. This also applies to the dosimeter positions on the fuel pins L1, L2, and L3 in run 1.

The flux distribution about the test hole center is sinusoidal in nature, as shown in figure 6. As expected, the highest flux occurs at the position nearest the core, while the lowest was measured facing north. On the center rod (location J) at 8 inches (20.3 cm) east of the core centerline, the flux levels range from 4.39×10^{13} neutrons/cm^2-sec at 0 degrees to 0.756×10^{13} neutrons/cm^2-sec at 180 degrees, a factor of 6 difference.

The effect of the rotation diminishes farther away from the core centerline. For example, at 23 inches (58.4 cm), the difference in the flux levels is only a factor of three. This occurs because the dosimeter position is beyond the edge of the core and the neutrons from the core are moving more in the direction of the HT-2 axis than perpendicular to it.

Another number of interest is the sum of the flux levels in the three capsules. This can be related to the total fission power produced in the capsules. The flux values used to compute the sum are those measured on the central rod (dosimeters J1-8, J2-8 and J3-8) at 8 inches (20.3 cm) east of the core centerline at the fuel pin midplane. The run 3 configuration resulted in the highest sum, since the capsules were the least distance from the core. Here, the sum of the flux in the three capsules was 6.80×10^{13} neutrons/cm^2-sec, of which the capsule at 0 degrees received 65 percent, while the capsules at 120 and 240 degrees received 18 and 17 percent respectively.

The configuration of run 2, which had all capsules at the greatest distance from the core, had the lowest sum with 5.94×10^{13} neutrons/cm^2-sec this is only 13 percent below the maximum. The capsules at 60 and 300 degrees received 45 and 42 percent of the total flux, while the capsule facing north receives only 13 percent.

Effect of three capsules. - By comparing run 3 with the single capsule tank tests (ref. 1), the effect of the additional experiment capsules was determined, since both runs had an experiment capsule in the same position. The difference between these runs, aside from the extra capsules, was that the single capsule had a molybdenum shell surrounding the fuel, which caused a 22 percent flux drop, and the single capsule had 27 grams of U^{235} instead of the 30 grams per capsule in the three-capsule tank tests.

The correction for the molybdenum was applied to both the D_2O and the H_2O runs of the single capsule tank before making a comparison with the three capsule tank tests. The results show that adding two capsules at 120 and 240 degrees lowers the flux at the centerline of a capsule at 0 degrees by 26 percent when using a D_2O tank. Similarly, at the centerline of a capsule nearest the core and surrounded by D_2O, the flux levels were from 50 to 100 percent higher than a single capsule surrounded by H_2O. The 50 percent difference occurred from 0 to 16 inches (0 to 40 cm) east of the core centerline, with the exception of the region near the fuel pins. In the fuel pin region and also from 16 to 28 inches (40 to 71 cm) east, the difference increased to about 100 percent. The capsule nearest the core had flux levels about 5 percent above the unperturbed H_2O measurements, and between 37 and 85 percent below the unperturbed void measurements. This is shown in figure 7.

The flux levels on the outside of the D_2O tank (locations A, B, C, and D) were almost the same for runs 1 and 2, so that these measurements along with those on the outside of the experiment capsules (locations F, G, H, and I) were omitted in run 3. Comparing these with the measurements on the outside of the single capsule D_2O tank, the following results were obtained. On the side facing the core, the flux levels were almost the same. Averaging the measurements from the top and the bottom to eliminate any effects of a slight rotation of the tank, the three capsule tank flux levels were 13 percent below the single capsule tank. On the north side of the bank, however, the flux levels dropped about 80 percent from the single capsule measurements. This results from the additional stainless steel added to the tank by the two extra experiment capsules between the core and the dosimeters, and from the lower volume of D_2O in the tank.

Effects of the fuel. - The presence of the fuel pins affects only the regions in the vicinity of the fuel. Effects at the center of the fuel, at the fuel pin surface and between the fuel pins are considered. These locations are at 8 inches (20 cm) east of the core center line.

On the aluminum rod passing between the fuel pins (location J), the flux drops about 26 percent. This value is an average of all three capsules and three runs. This compares with a value of 32 percent obtained from the single capsule tests. The flux depression is slightly lower because in the three capsule fuel assemblies the fuel pins contain more fuel, but the fuel is slightly further away from the center rod than in the single capsule. The net result is a reduced flux depression due to the fuel. The flux drop is calculated by the following method. First, the measured fluxes along the center rod are plotted as in figure 7, with the exception of the values near the fuel. A curve is then fitted to the points on both sides of the fuel. This is the approximate flux distribution without the fuel. The measured flux value at the fuel midplane is then compared to the interpolated value, resulting in the perturbation due to the fuel.

The ratio of the flux incident on the fuel surface to the flux inside the fuel is 3.2:1. This is an average over all capsules and runs, and is 10 percent higher than the single capsule value of 2.9:1 (ref. 1). This difference could be due to the 10 percent greater fuel mass in the three capsule fuel pins. Because the dosimeters were mounted on the outside of the stainless steel tube mocking up the coolant gas flow guide, a 10 percent correction was applied to account for the flux drop through the tube wall (ref. 1).

In run 1, the fuel pins L1, L2, and L3 had four dosimeters mounted on the flow guide tube at 90 degree intervals at the fuel midplane. The results of these measurements are shown in figure 8, showing that the flux measurements made by the dosimeters mounted so that they face the core will result in values 11.5 percent higher than the average. All dosimeters on the fuel pins in all three runs except pins L1, L2, and L3 in run 1 were mounted in this fashion. Figure 8 also shows that the flux measured on the circumference of the fuel pin can vary by ±12 percent relative to the average flux depending on the location of the dosimeter on the fuel pin surface.

The effectiveness of the three capsule tank may be measured by comparing both the flux measured in each capsule, and the sum of the flux levels in all three capsules with the flux measured in a single capsule configuration. For this comparison, the flux measured on the center rod between the fuel pins at 8 inches (20.3 cm) east of the core centerline was chosen. For example, the sum of the flux levels in the three capsules surrounded by D_2O was 1.3 times greater than the flux in a single capsule in D_2O. Likewise, comparison with a single capsule surrounded by H_2O, which is the typical test configuration, shows that the sum of the flux levels in the three capsule cluster in D_2O is 3.1 times greater. In the configuration of run 3 (see fig. 5) which has the highest flux levels, the capsule nearest the core has flux levels about 2 times higher in the fuel pin region than a single capsule in H_2O. The flux in each of the two remaining capsules is about one half of the flux in the single capsule in H_2O.

Gamma Heating Distribution

Gamma heating measurements were made only on the center rod of capsule 2 in run 1. The results, along with measurements for the unperturbed test hole, are shown in figure 9. The measurements of this study appear to correlate with the measurements in the unperturbed, voided test hole. Figure 9 shows a discontinuity in the fuel pin region. This results from the high gamma heating due to the secondary gamma radiation from fissions in the fuel pins, which saturated the dosimeters at 5 watts/gram, preventing measurement of gamma heating in this region.

SUMMARY OF RESULTS

Three experiments were run in the HT-2 test hole of the Plum Brook Mock-up Reactor. The experiments used three identical test sections in a D_2O tank. The effect of the angular position of the capsule about the HT-2 center line, the effect of adding two capsules to a tank previously containing a single capsule, and the effect of the fuel on the flux distribution within the experiment capsules was determined. The following results were obtained:

1. The flux distribution about the test hole axis as measured at the experiment capsule center line is sinusoidal in nature. At the fuel midplane, the flux levels range from 4.39×10^{13} neutrons/cm^2-sec for a capsule facing the core to 0.756×10^{13} neutrons/cm^2-sec when the capsule faces away from the core. This is a factor of 6 difference.

2. The sum of the flux in the three capsules when they are furthest from the core is only 13 percent below the sum of the flux when they are nearest the core.

3. In a three capsule D_2O tank, the capsule nearest the core has a flux level which is 26 percent lower than an identical capsule in a single capsule D_2O tank, and two times higher than a single capsule in H_2O.

4. Ninety grams of U^{235} fuel contained in nine fuel pins with 5 grams of U^{235} per inch (2 grams of U^{235} per cm) resulted in the following flux perturbation. The presence of the fuel in the fuel pins lowers the flux measured on the rod passing between the fuel pins by 26 percent at the fuel pin midplane. The ratio of the flux measured at the surface of the fuel pin to the flux at the center of the fuel pin was 3.2:1. The flux measured on the surface of the fuel pin varied by ±12 percent relative to the average, depending on the circumferential position of the dosimeter. Dosimeters mounted on the fuel pins so that they faced the core measured flux level 11.5 percent higher than the average flux received by the fuel pin.

5. The sum of the flux levels in the three capsules was 1.3 times higher than the flux in a single capsule in D_2O, and 3.1 times higher than the flux in a single capsule in H_2O.

6. Gamma heating measurements show that at the capsule centerline the gamma heating ranges from 2.3 watts/gram at 3 inches (7.6 cm) east of the reactor core centerline to 1.40 watts/gram at 13 inches (33.0 cm) east. The gamma heating near the fuel pins was greater than 5 watts/gram due to fissioning in the fuel pins.

CONCLUDING REMARKS

In a three capsule tank, the two capsules away from the core have lower flux levels than the capsule near the core. However, since these two capsules would probably operate at lower power and pressure than the capsule near the core, they could be made more effective by making the capsule wall out of aluminum or thinner stainless steel. This should raise the flux level in each capsule at least to that of a single capsule in H_2O. This estimate is based on the perturbation for the stainless steel liner measured in reference 1. This change should increase the sum of the flux in the three capsules to about 1.7 times the flux in the single capsule with D_2O.

This effect can be used to advantage in the circulating gas capsule tests (ref. 3). The capsule facing the core will have a high flux and power level and require 1000 to 2000 psi of gas pressure, and must be made out of stainless steel. The remaining two capsules will have lower flux and power levels and therefore need lower gas pressures (500 to 1000 psi), so that they can be made from aluminum or thin wall stainless steel. This could increase the sum of the flux in the three capsules to over 4 times the flux in a single capsule surrounded by water.

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TABLE I.- THERMAL NEUTRON FLUX MEASURED AT THE EXPERIMENT CAPSULE CENTER LINE AND THE FUEL PIN SURFACE AND CENTER.

Dosimeter location	Dosimeter station number	Thermal neutron flux at 60 MW, neutrons/cm^2-sec x 10^{13}								
		Angular position of the experiment capsule, degrees								
		0	60	90	120	180	210	240	300	330
J	0.5	7.94	4.54	3.04	2.17	1.31	1.56	2.00	4.39	6.58
	3	6.56	4.05	2.80	1.94	1.13	1.32	1.86	3.77	5.64
	4	6.31	3.96	2.71	1.93	1.17	1.29	1.83	3.76	5.33
	5	6.16	3.74	2.58	1.90	1.09	1.30	1.69	3.74	5.21
	6	6.00	3.70	2.58	1.80	1.07	1.22	1.61	3.57	5.06
	7	4.95	3.03	2.11	1.54	0.798	1.05	1.42	2.91	4.15
	8	4.39	2.66	1.89	1.23	.756	0.862	1.18	2.52	3.29
	9	4.52	2.86	2.10	1.40	.841	.891	1.17	2.71	3.64
	10	4.73	3.07	2.22	1.49	.885	.962	1.41	2.89	3.95
	11	4.53	2.86	2.07	1.42	.793	1.00	1.32	2.71	3.74
	12	4.20	2.51	1.87	1.31	.786	0.940	1.27	2.30	3.33
	13	3.94	2.36	1.65	1.23	.737	.860	1.18	2.14	3.04
	16	2.57	1.70	1.14	0.898	.533	.585	0.828	1.53	2.09
	18	-	1.18	0.830	-	.433	.454	-	1.06	1.44
	20	1.21	0.743	.584	.498	.296	.315	.485	0.731	0.938
	23	0.558	.394	.267	.288	.174	.179	.271	.341	.449
	27	.192	.107	.111	.093	.075	.073	.097	.115	.148
	31	.090	.068	.053	.067	.036	.033	.050	.056	.062
Surface of the fuel pins										
K	8	-	2.55	1.72	-	0.734	0.805	-	2.45	3.53
L	8	4.19	2.58	1.52-S 1.55-T 1.28-B 1.17-N	1.28	0.636	0.941-S .964-T .821-B .709-N	1.10	2.44	3.77-S 3.97-T 2.52-B 2.77-N
M	8	-	1.93	1.74	-	0.738	0.740	-	1.86	2.54
Avg.	8		2.35	1.61		0.702	0.801		2.25	3.11
Center of the fuel pins										
K	8	-	0.705	0.439	-	0.184	0.263	-	0.815	0.930
L	8	-	0.686	0.403	-	0.188	0.263	-	0.740	0.880
M	8	-	0.496	0.478	-	0.202	0.297	-	0.756	0.614
Avg.	8	-	0.629	0.440	-	0.191	0.274	-	0.770	0.808

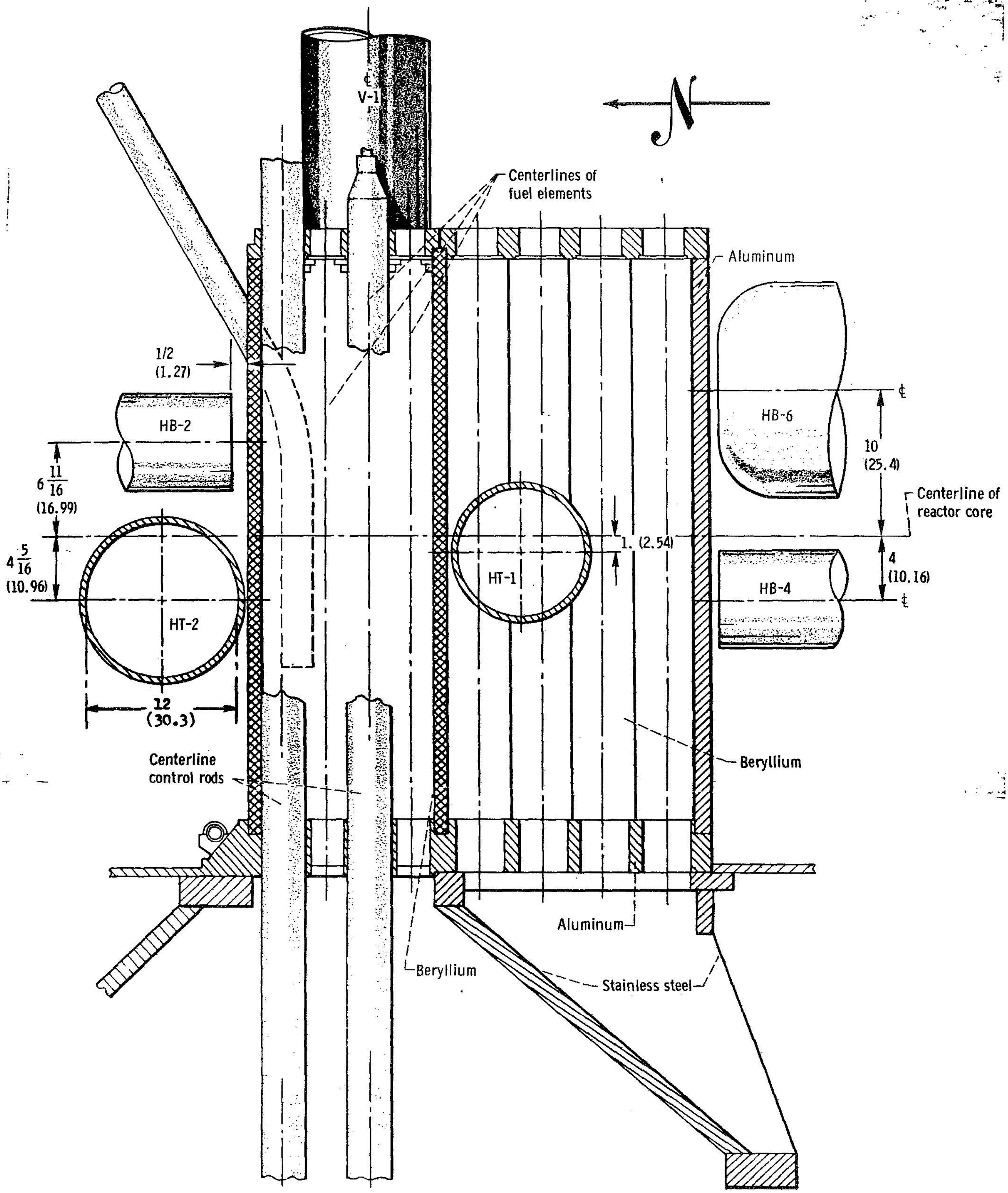
S - south B - bottom
T - top N - north

TABLE II. - THERMAL NEUTRON FLUX MEASUREMENTS FOR RUNS 1 AND 2 MEASURED ON THE EXPERIMENT CAPSULES AND THE D_2O TANK.

Dosimeter location	Thermal neutron flux, neutrons/ cm^2 - sec x 10^{13} at 60 MW							
	Station number							
	0	4	8	12	16	20	24	28
	Run 1, measurements on the experiment capsules							
F1	6.67	6.32	5.75	4.34	2.73	1.21	0.427	0.138
G1	3.01	2.83	2.66	2.23	1.38	0.694	.259	.102
H1	2.33	2.27	1.86	1.64	1.10	.586	.244	.098
I1	3.72	3.76	3.08	2.63	1.64	.792	.316	.113
F2	14.60	12.20	11.30	8.08	4.71	1.99	.553	.151
G2	7.85	6.73	5.93	4.55	2.76	1.21	.421	.132
H2	4.65	4.02	3.14	2.69	1.63	0.821	.310	.114
I2	6.65	5.99	5.45	4.17	2.42	1.14	.403	.143
F3	2.79	2.72	2.21	1.88	1.23	0.590	.254	.096
G3	1.78	1.72	1.42	1.26	0.833	.447	.206	.080
H3	1.18	1.23	1.10	0.903	.661	.354	.174	.074
I3	1.77	1.96	1.65	1.38	.904	.479	.220	.086
	Run 1, measurements on the D_2O tank surface							
A	24.40	22.60	21.70	15.4	8.59	3.60	0.835	0.218
B	3.54	3.75	3.64	2.84	1.66	0.838	.350	.114
C	1.07	1.35	1.20	1.00	0.717	.392	.185	.074
D	3.51	3.85	3.48	2.69	1.73	.829	.354	.134
	Run 2, measurements on the experiment capsules							
F1	2.44	2.41	2.04	1.69	1.11	0.572	0.249	0.091
G1	1.50	1.51	1.35	1.14	0.840	.443	.205	.083
H1	1.10	1.18	1.00	0.907	.630	.376	.167	.071
I1	1.71	1.77	1.55	1.30	.913	.504	.219	.089
F2	10.50	9.40	8.62	6.53	3.91	1.65	0.529	0.152
G2	4.67	4.30	3.80	3.00	1.82	0.882	.340	.118
H2	3.41	3.20	2.52	2.28	1.47	.748	.307	.112
I2	5.50	5.32	4.58	3.64	2.22	1.05	----	.132
F3	10.30	9.60	8.70	6.43	3.72	1.46	0.518	0.150
G3	5.10	4.60	4.01	3.20	1.96	0.917	.338	.116
H3	3.20	2.99	2.41	2.03	1.34	.744	.294	.106
I3	5.18	4.97	4.40	3.42	2.01	.973	.376	.127
	Run 2, measurements on the D_2O tank surface							
A	3.36	3.44	3.43	2.70	1.73	0.893	0.361	0.134
B	0.914	1.21	1.07	0.937	0.645	.373	.168	.073
C	3.52	3.78	3.43	2.60	1.68	.797	.331	.119
D	25.00	23.70	22.20	16.40	8.40	3.59	.896	.245

TABLE III. - GAMMA HEATING MEASUREMENTS AT THE CENTER LINE OF THE EXPERIMENT CAPSULE NO. 2 (J2) IN RUN 1.

Dosimeter station number	Gamma heating, watts/gram at 60 MW
2.9	2.30
4	2.29
5	2.20
5.5	2.17
6	> 5.0
6.9	> 5.0
8	> 5.0
8.5	> 5.0
9	4.89
10	1.69
11	1.69
12	1.46
13	1.40



(a) Side view at core north-south vertical midplane.

Figure 1. - Mockup reactor. (All dimensions are in inches (cm).)

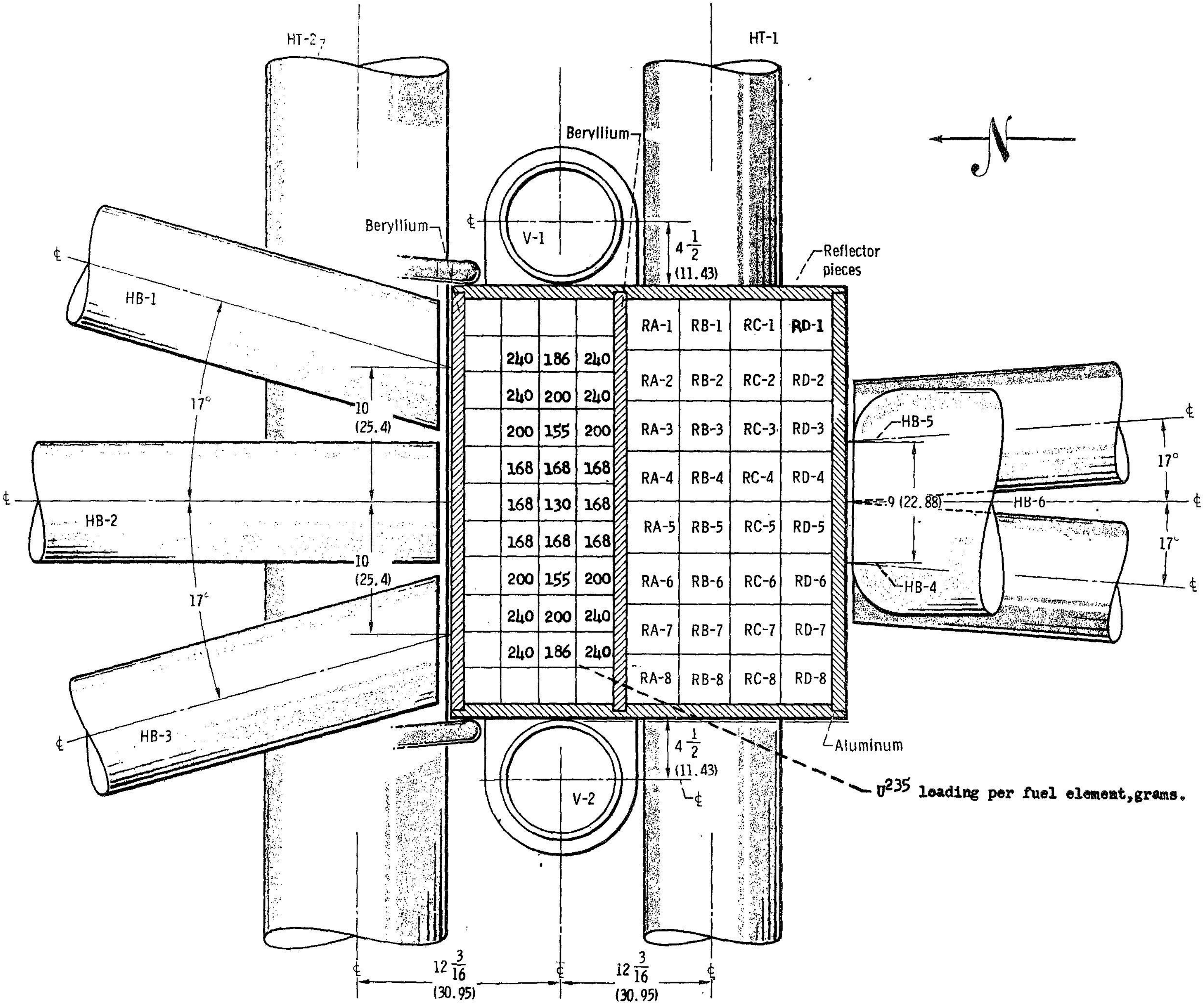


Figure 1(b) Horizontal plan view.

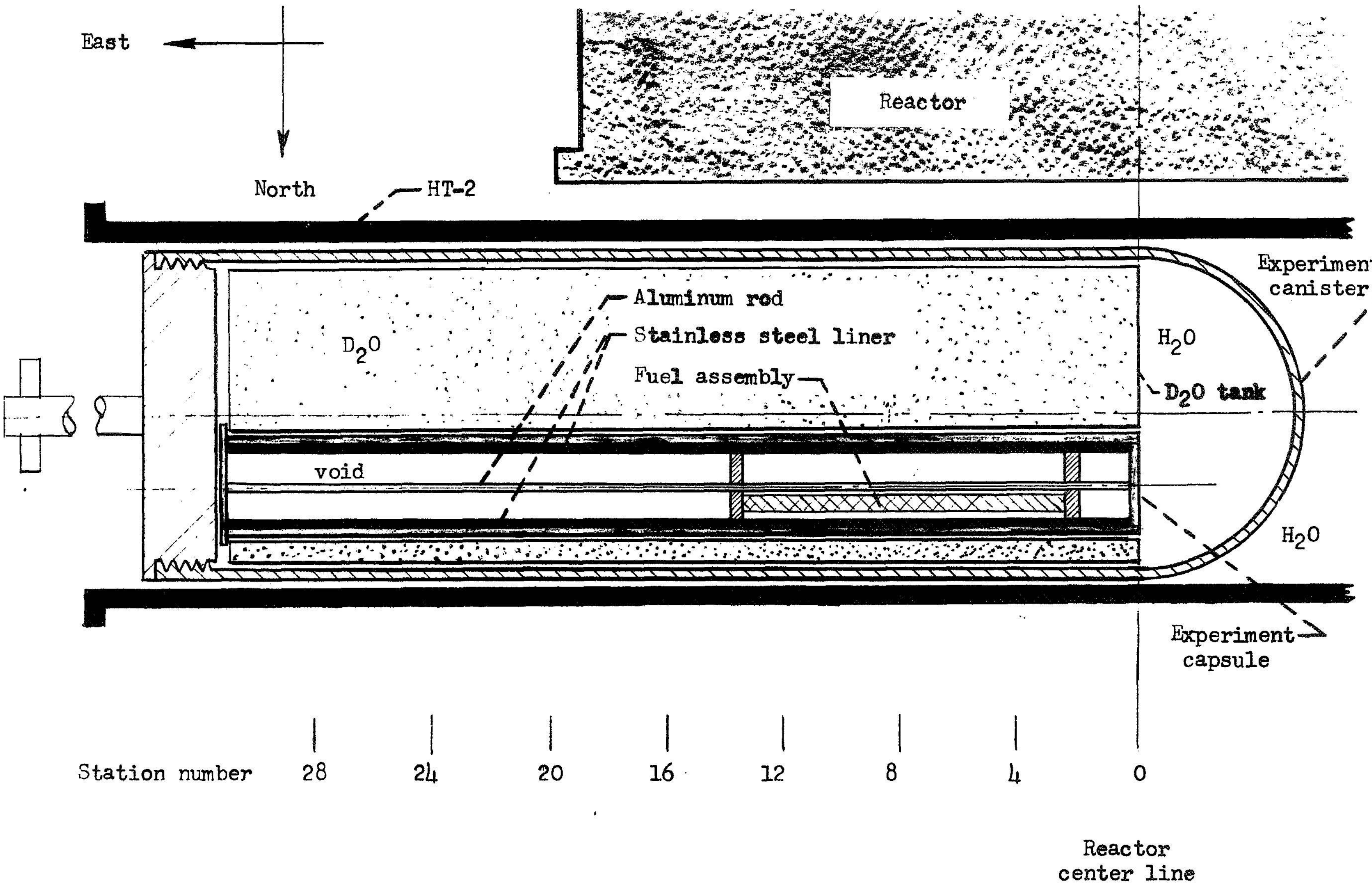


Figure 2. - Top view of the experiment apparatus with fully inserted capsule.
(One of three capsules shown)

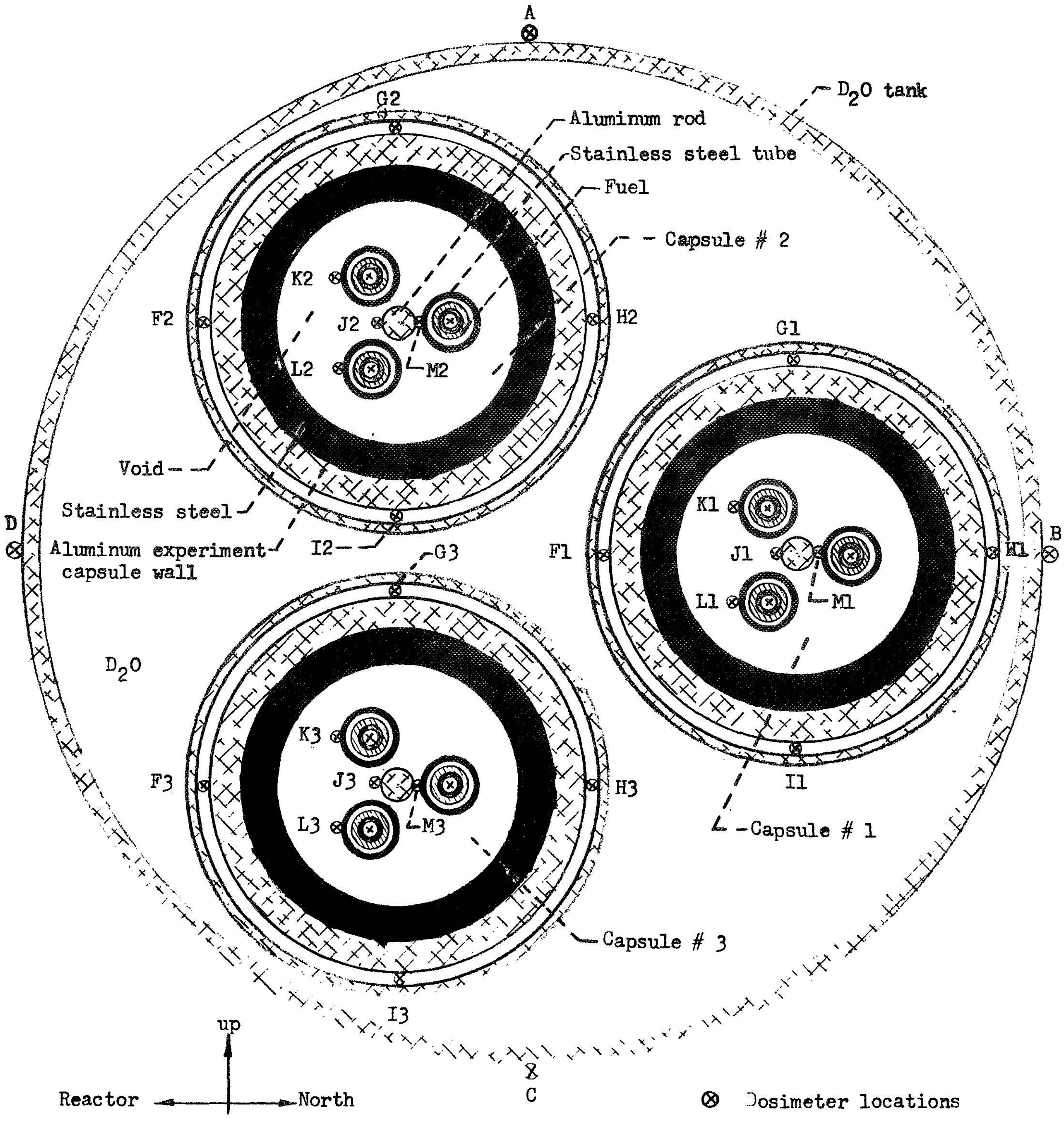


Figure 3. - Cross section of the D_2O tank and experiment capsules, showing the dosimeter locations. (Run 2 configuration)

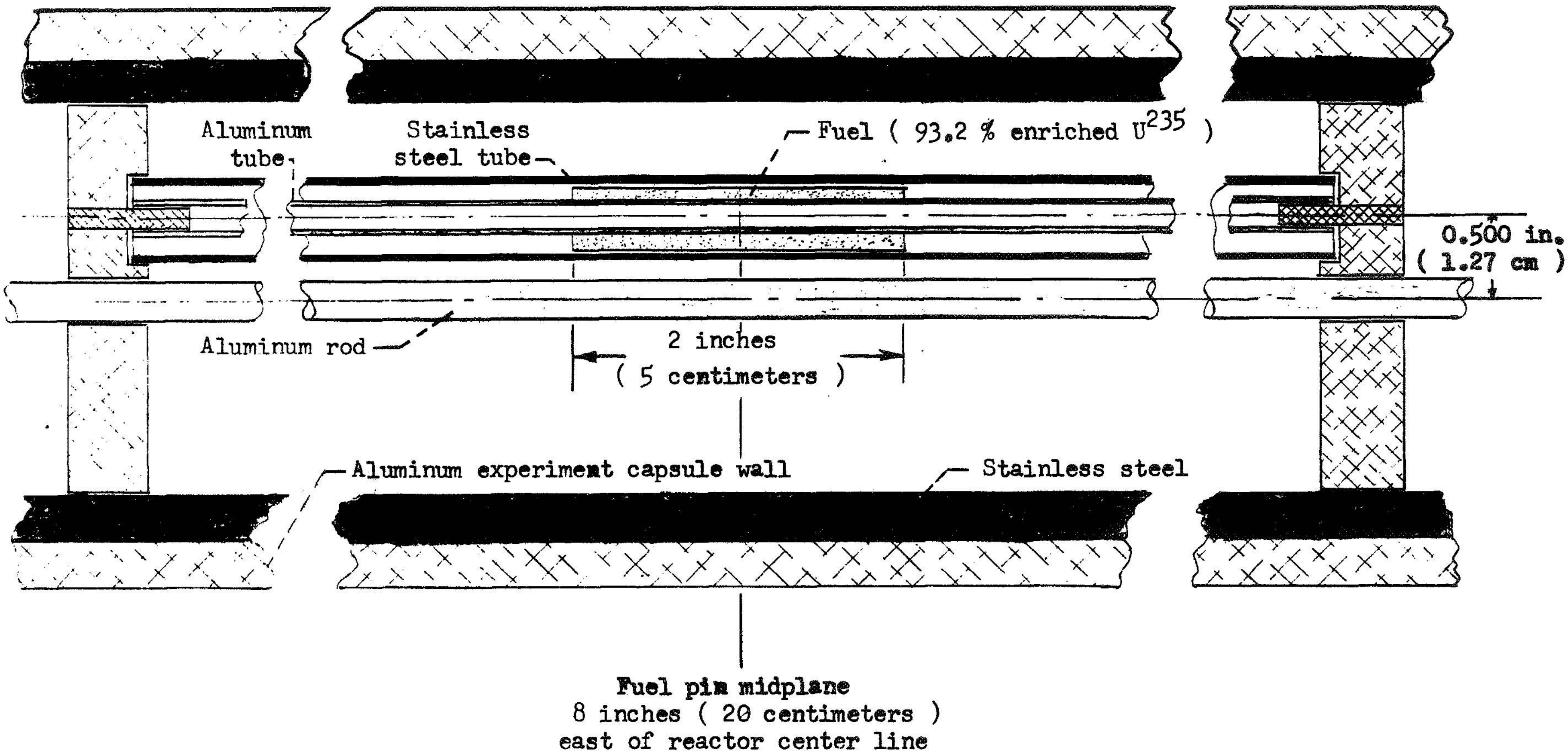


Figure 4. - Details of the fuel assembly.

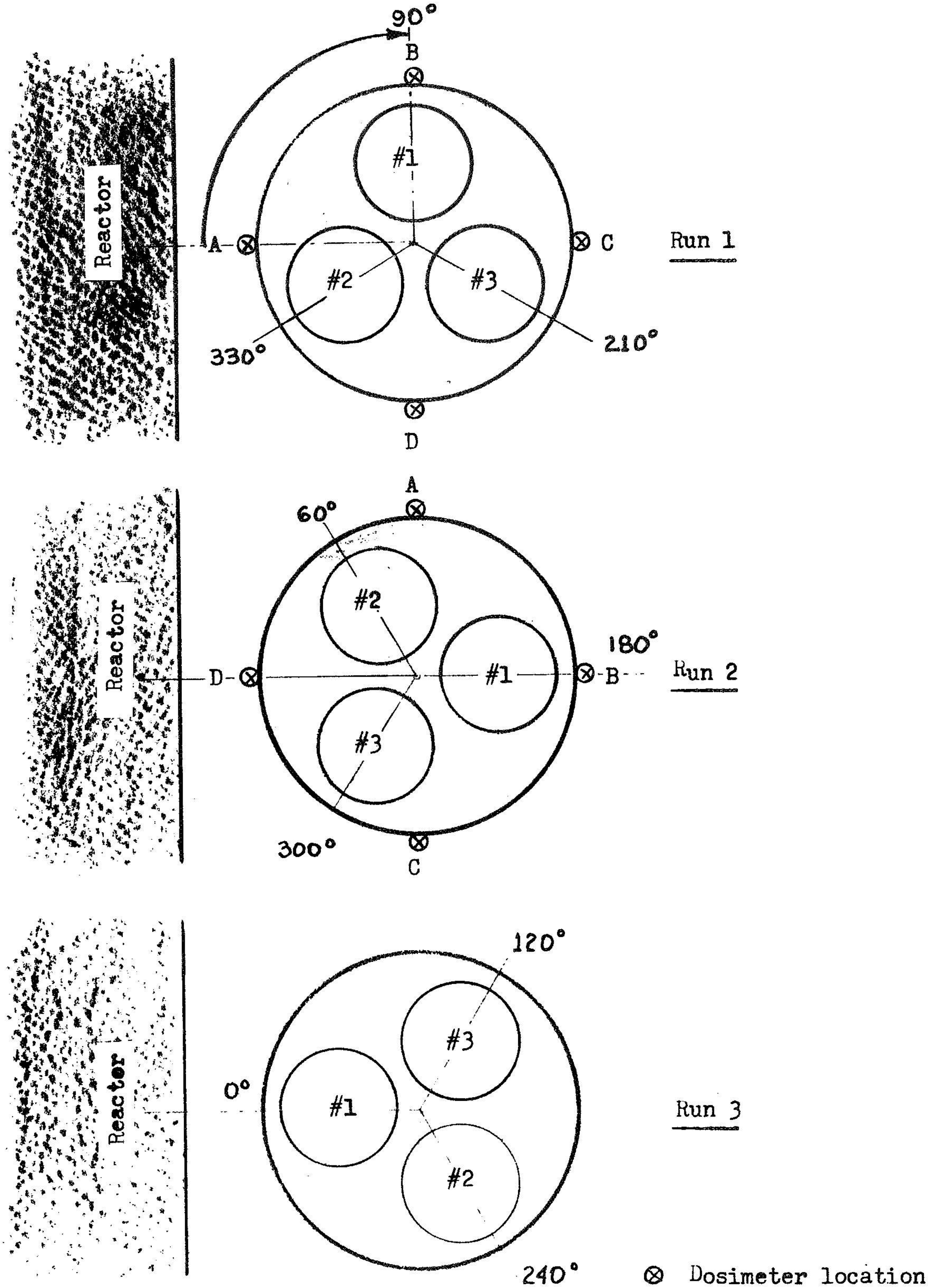


Figure 5.- View along HT-2 axis showing the positions of the D_2O tank and the experiment capsules and the dosimeter locations for runs 1 to 3. (No dosimeters were mounted on the tank surface in run 3)

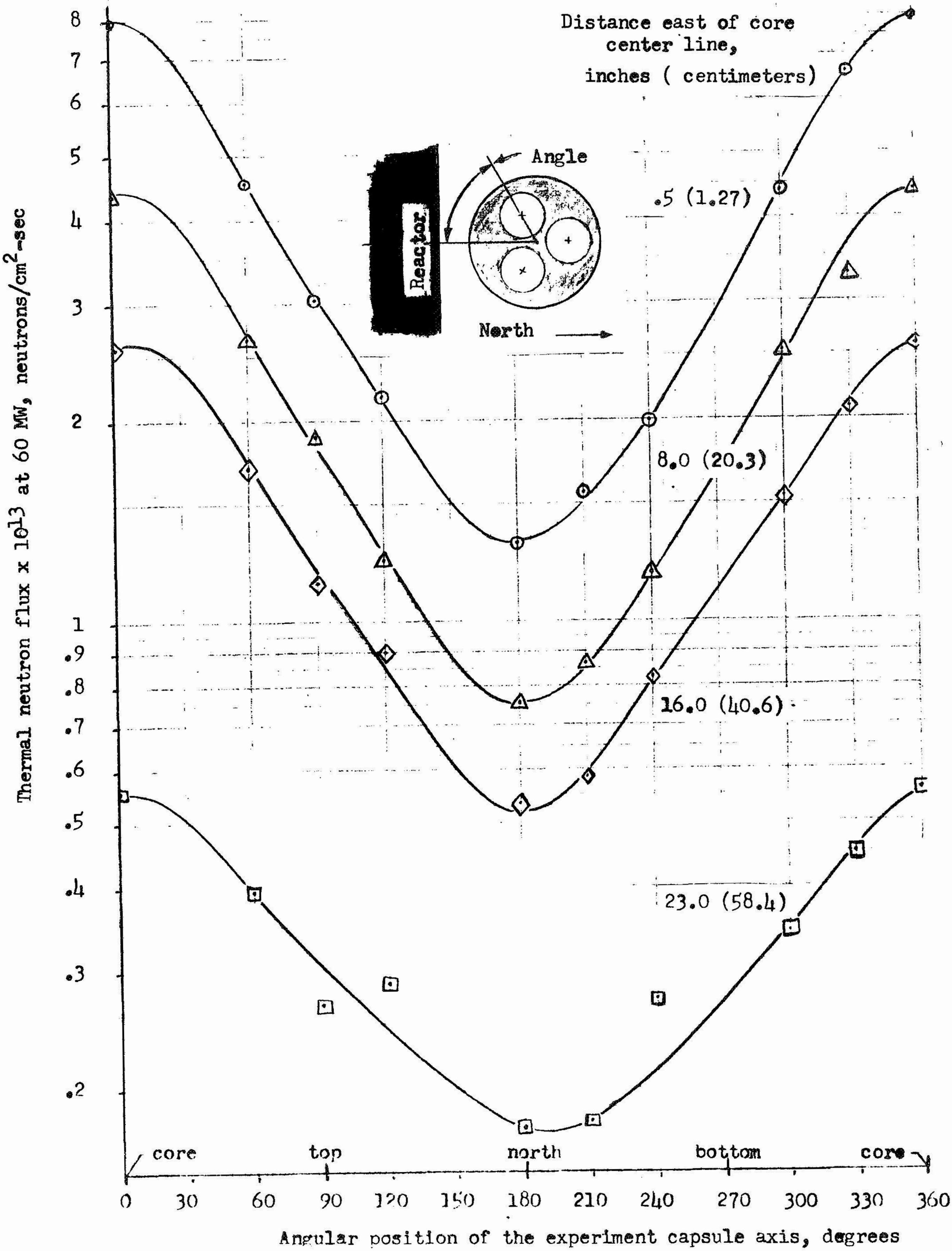


Figure 6. - Thermal neutron flux at the experiment capsule axis as a function of the angular position about the HT-2 axis and distance east of the core centerline.

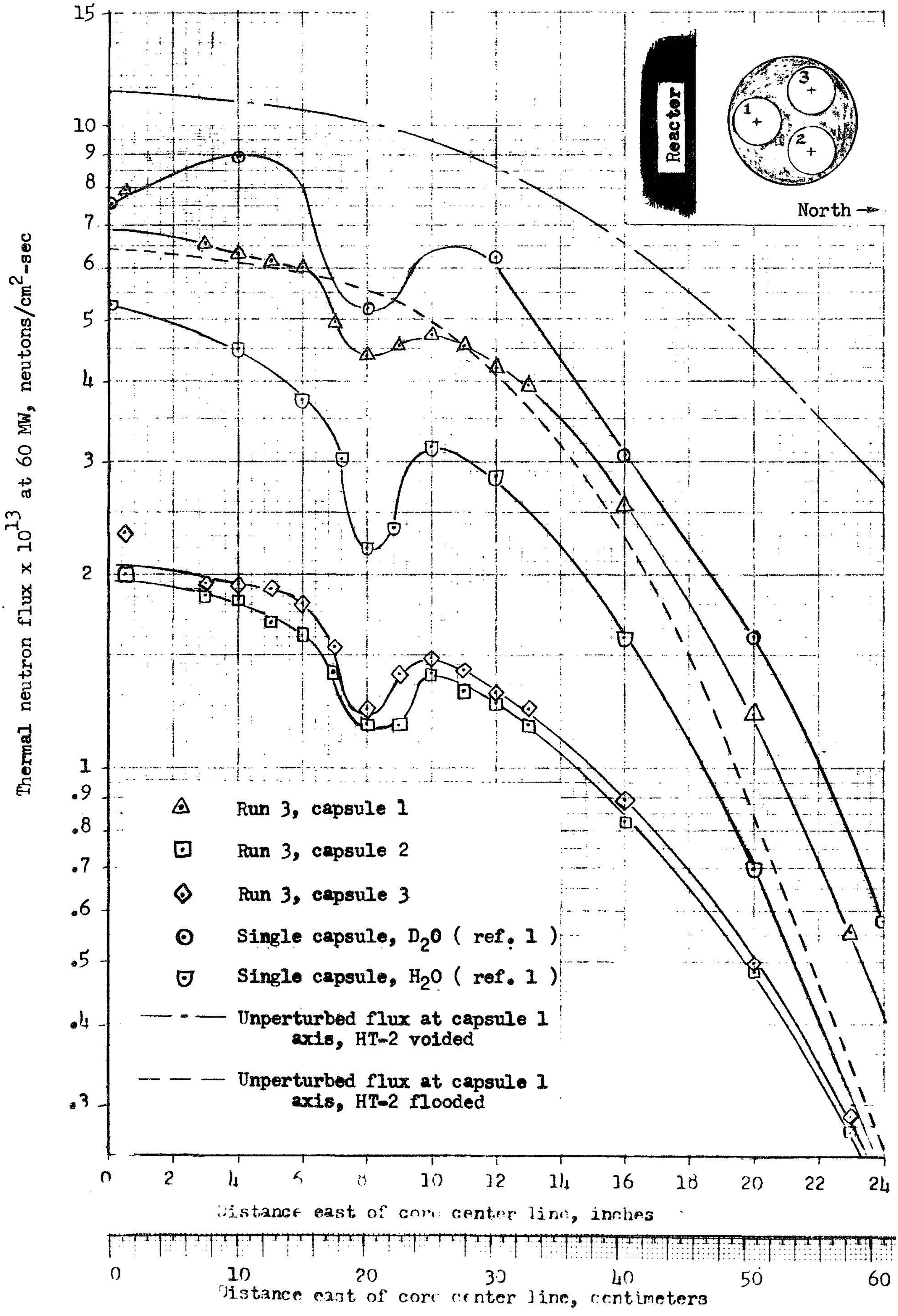


Figure 7.- Thermal neutron flux distribution as a function of distance east of the reactor core centerline, as measured on the experiment capsule axi

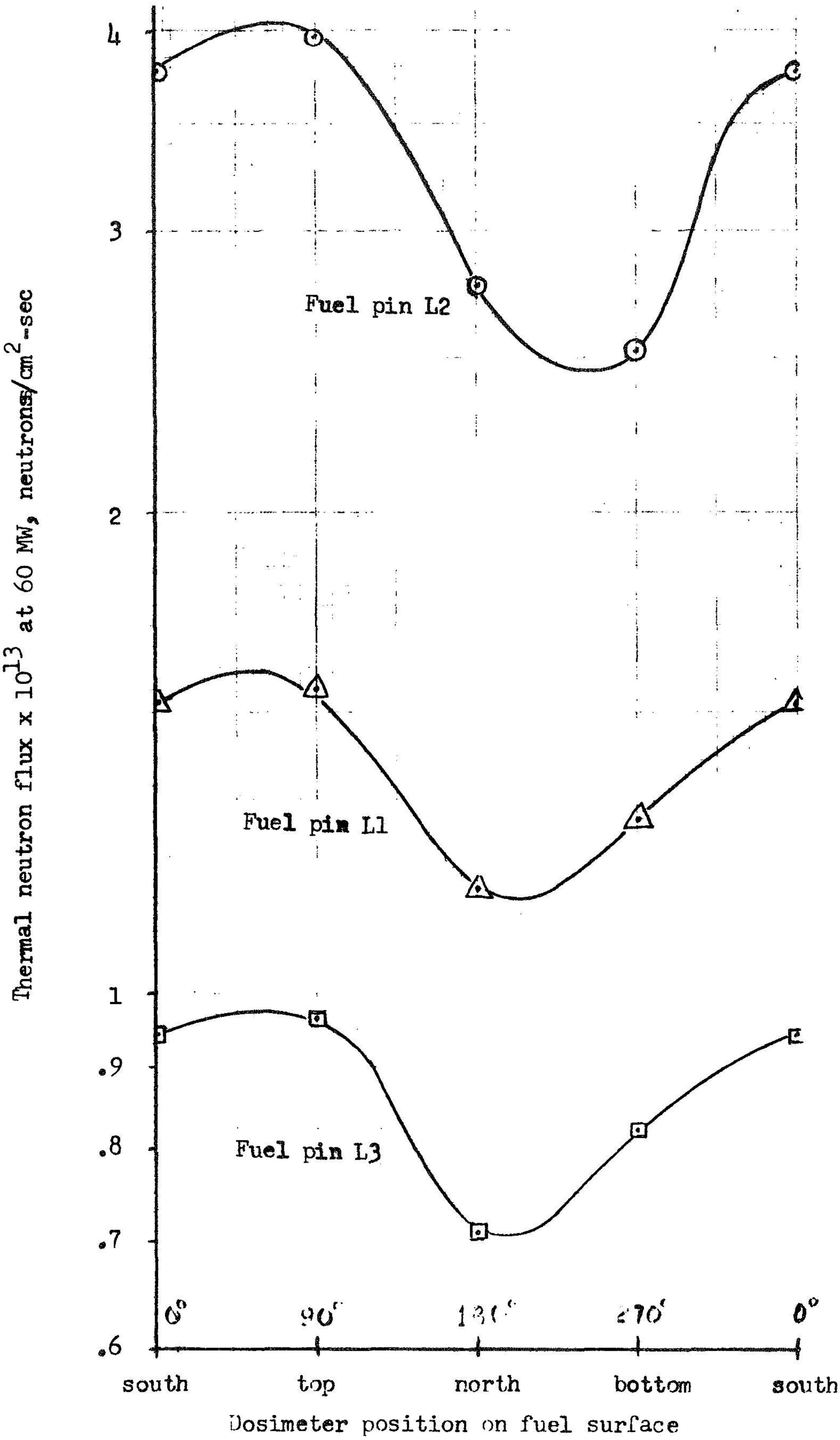


Figure 8. - Thermal neutron flux as a function of dosimeter position measured on the surface of fuel pins L1, L2, and L3 at the fuel midplane 8 inches (20 centimeters) east of the reactor core center line. Run 1.

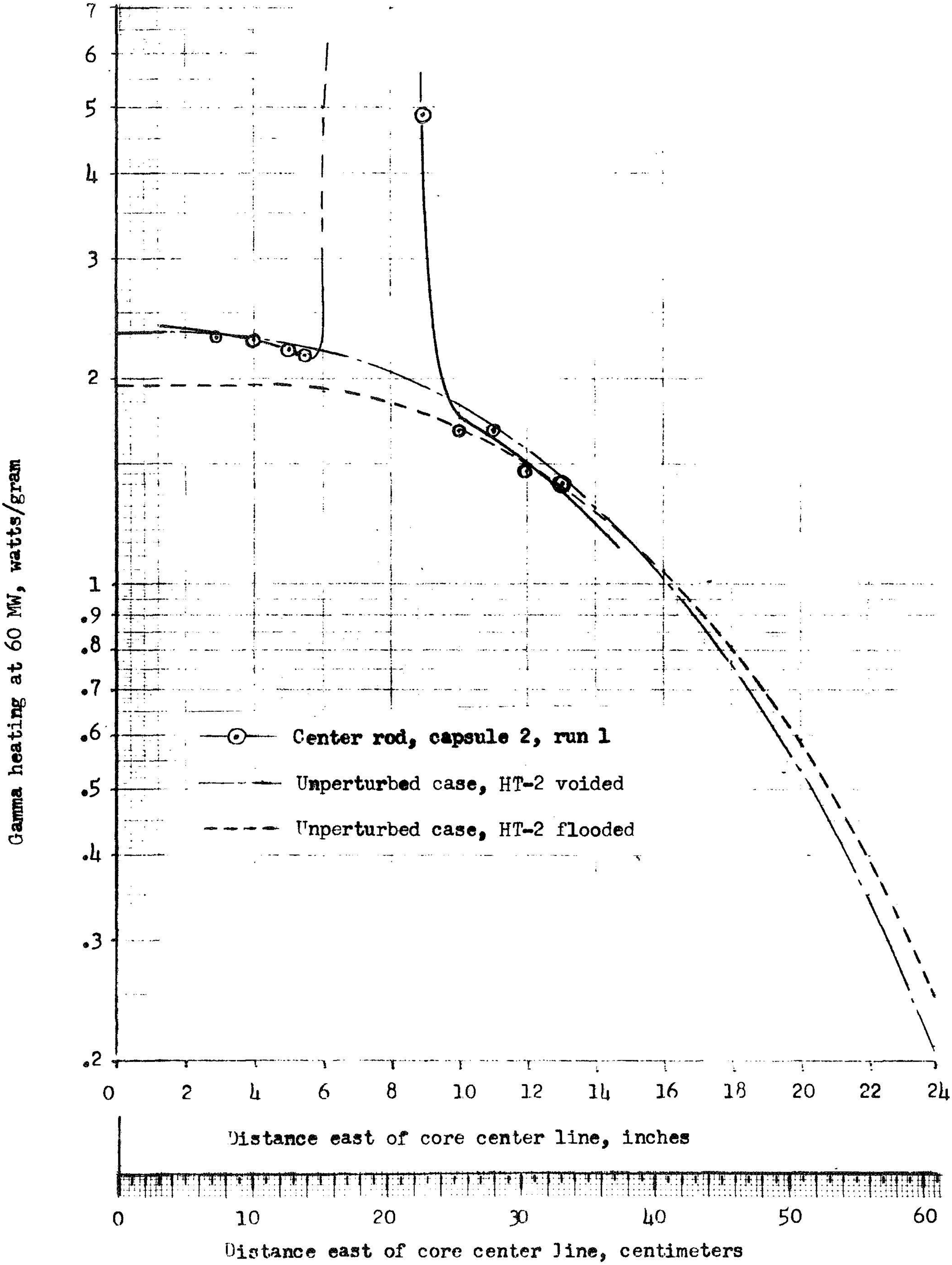


Figure 9. - Gamma heating as a function of the distance east of the reactor core center line.